ARE LEAF CHEMISTRY SIGNATURES PRESERVED AT THE CANOPY LEVEL?

Christoph C. Borel and Siegfried A.W. Gerstl

Los Alamos National Laboratory, MS D 436
Los Alamos, New Mexico 87545, USA

August 1994

Contents :

1. Introduction
2. Modeling Requirements
3. Tree Reconstruction
4. Walnut Tree Experiment
5. Spectra for Simple Canopies
6. Signature of Complex 3D Canopies
7. Conclusions
8. References

Introduction

Problems :

- How does the canopy architecture change the leaf chemical signature and by how much?
- Effects due to illumination, background and terrain on the spectral signatures.

Qualitative Answer :

- The scattered light from a single phytoelement will interact with many others before it leaves the canopy
- Multiple reflections and transmissions modify the original leaf spectrum
- The magnitude of spectral changes depends on the canopy architecture and the external illumination direction.

Modeling Requirements

Model must consider :

1. Discrete phytoelements (leaves, needles, stems, fruits, etc.) with specified size, location, orientation, reflectance and transmittance.
2. Transmission and multiple reflections between leaves must be taken into account.
3. Direct and indirect illumination.
4. Shadowing within the canopy and on the ground.
5. Calculation at any wavelength with spectrum transfers between leaves must be possible.

→ **Choose Radiosity Method**

Tree Reconstruction

Necessary tree architecture measurements :

Number of Orders of Branching This characteristic can be determined by visual examination of a tree and simply counting the number of times branching occurs from the trunk to the most apical stems.

Branching Order of Leaf Bearing Stems The branching order of stems which bear leaves may be recorded. There are likely to be several orders which bear leaves.

Stem Level Parameters :

Stem Diameter Diameter at the mid-length of a stem may be measured with a ruler.

Stem Length The length of a stem may be measured with a ruler or tape.

Number of Leaves per unit Length of Stem For leaf bearing stems, the number of leaves (or needle fascicles) can be counted so that the number of leaves per unit length of leaf bearing stem may be determined.

Branching Angle The angle of divergence between stems at all orders higher than 1, can be estimated with a protractor.

Phyllotaxis Angle For coniferous trees (or those with strong monopodial growth), the azimuthal angle of divergence from the main stem can be estimated with the help of a compass.

Walnut Tree Experiment

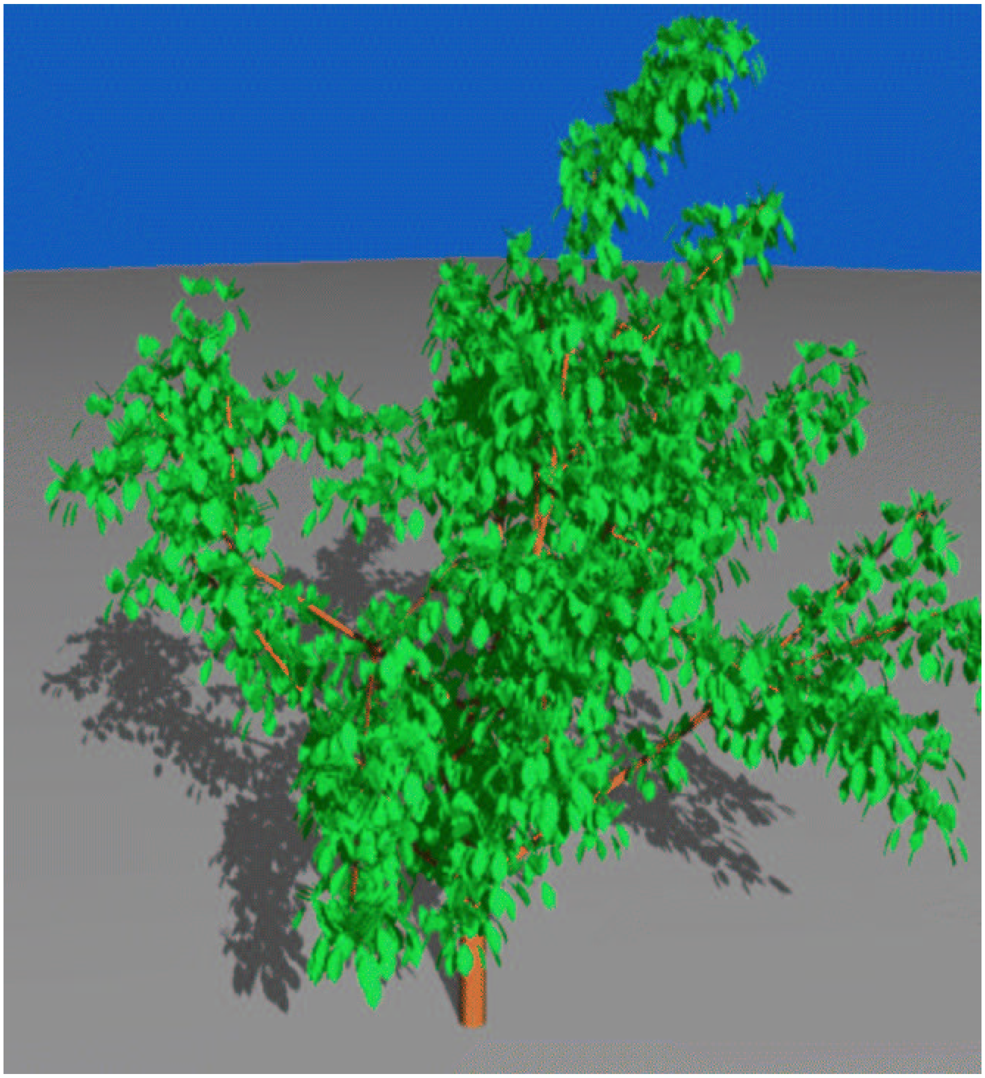


Figure 1: Reconstructed walnut tree rendered using raytracing

Example of a linked list :

Linked List					
Segment Number	Parent Segment	Length in cm	Diam. in cm	Stem Zen.	Stem Azi.
1	0	77	13.9	0	0
2	1	59	6.5	51	180
3	1	192	6.0	45	81
4	1	65	5.0	51	355
5	1	76	11.8	13	345
6	2	20	5.2	55	155
...	...	...	...	...	...

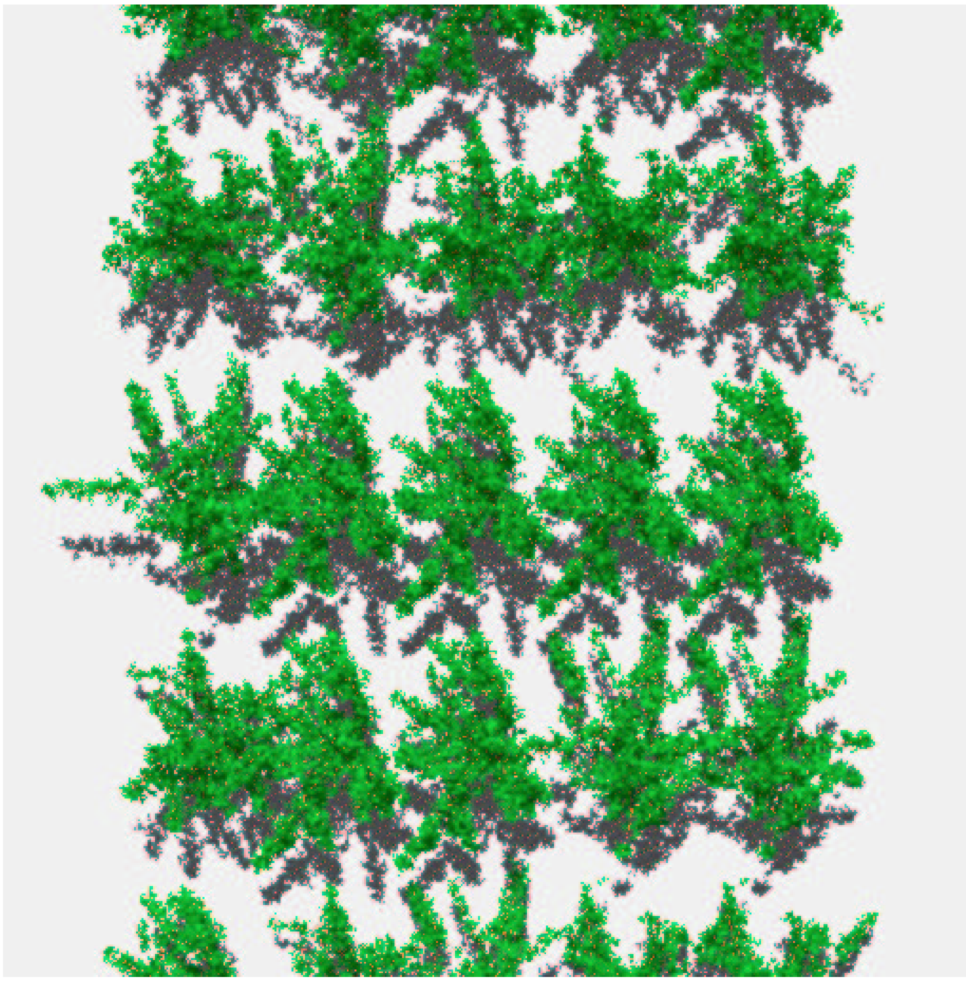
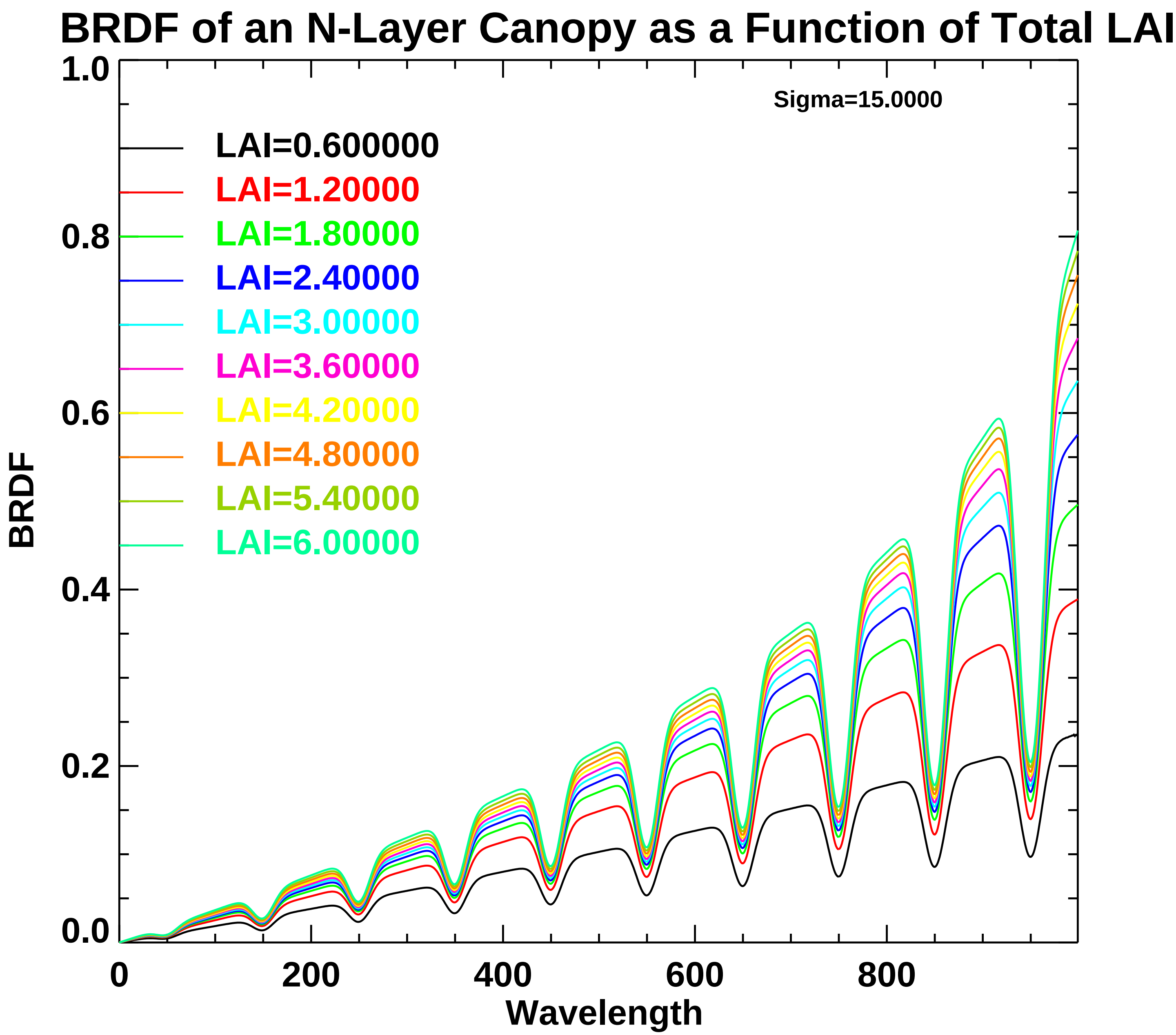


Figure 2: Portion of a walnut orchard rendered using raytracing

Spectra for Simple Canopies

A simple model using artificial absorption features was developed to show the effect of non linear spectral mixing :

- Let $\rho = \tau$ be a linear function of wavelength from 0. to 0.5 and add 10 absorption features with a mean and standard deviation (Sigma)
- Compute BRDF of a layered canopy with $N = 10$ layers for 10 leaf layers from .1 to .6 per layer



Borel and Gerstl, LANL

Signature of Complex 3D Canopies

Hybrid Model :

- Simple and fast
- Conventional radiosity method would need matrix 10^6 by 10^6

Steps :

1. Raytrace images of a part (2 m x 2 m) of a reconstructed walnut tree for a given geographical location (e.g. Maricopa, Los Alamos, 45^0 North) and dates (e.g. 3-21, 5-26, 6-21) and given times (e.g. every hour from 8 am to 4 pm) for nadir view or off-nadir views ($\theta_v = -40^0, -30^0, .., +30^0, 40^0$).

2. Compute image statistics such as :

- Probabilities of seeing illuminated surfaces :

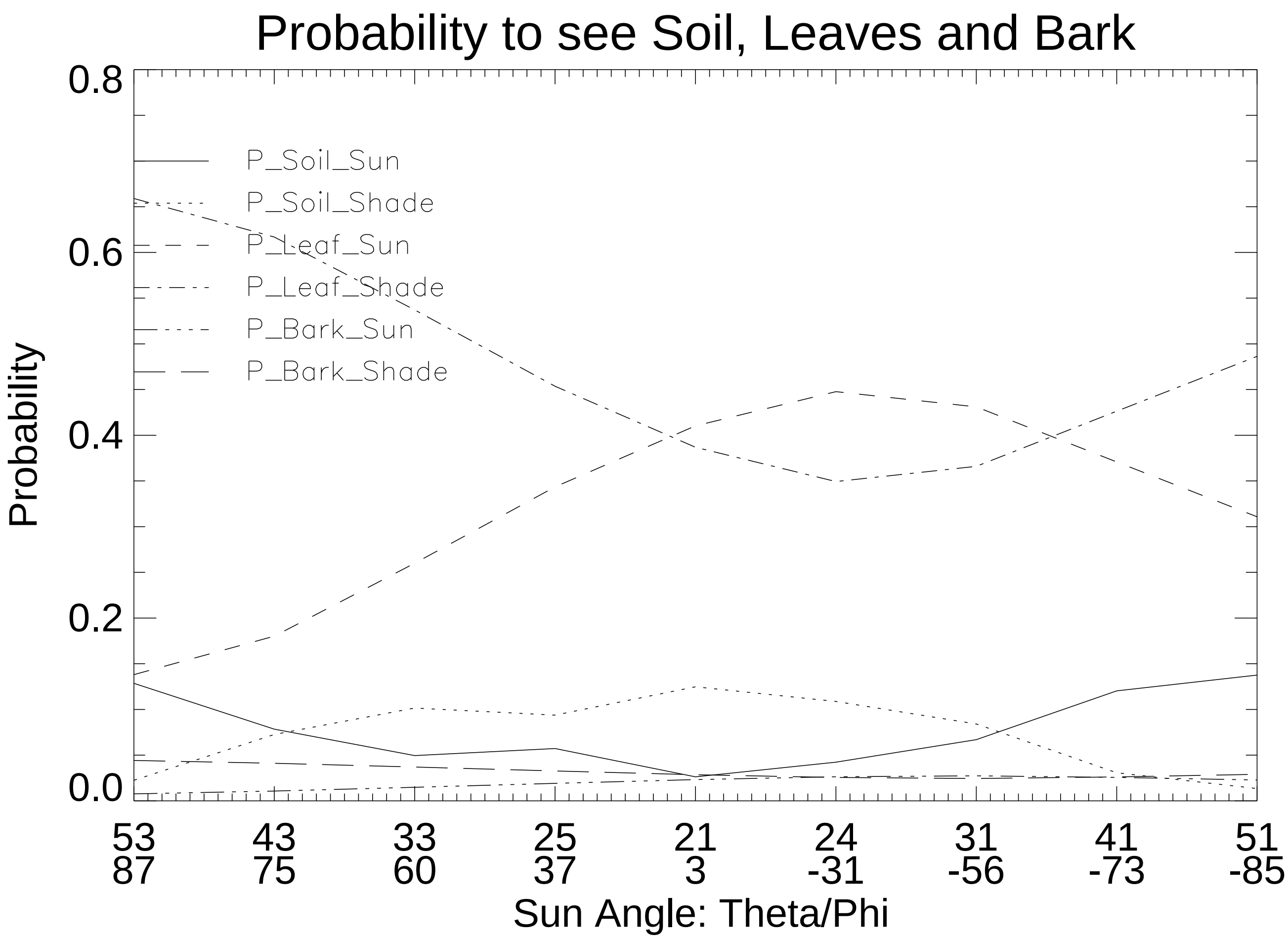
  P^{sun}_{leaf}, P^{sun}_{bark}, P^{sun}_{soil}

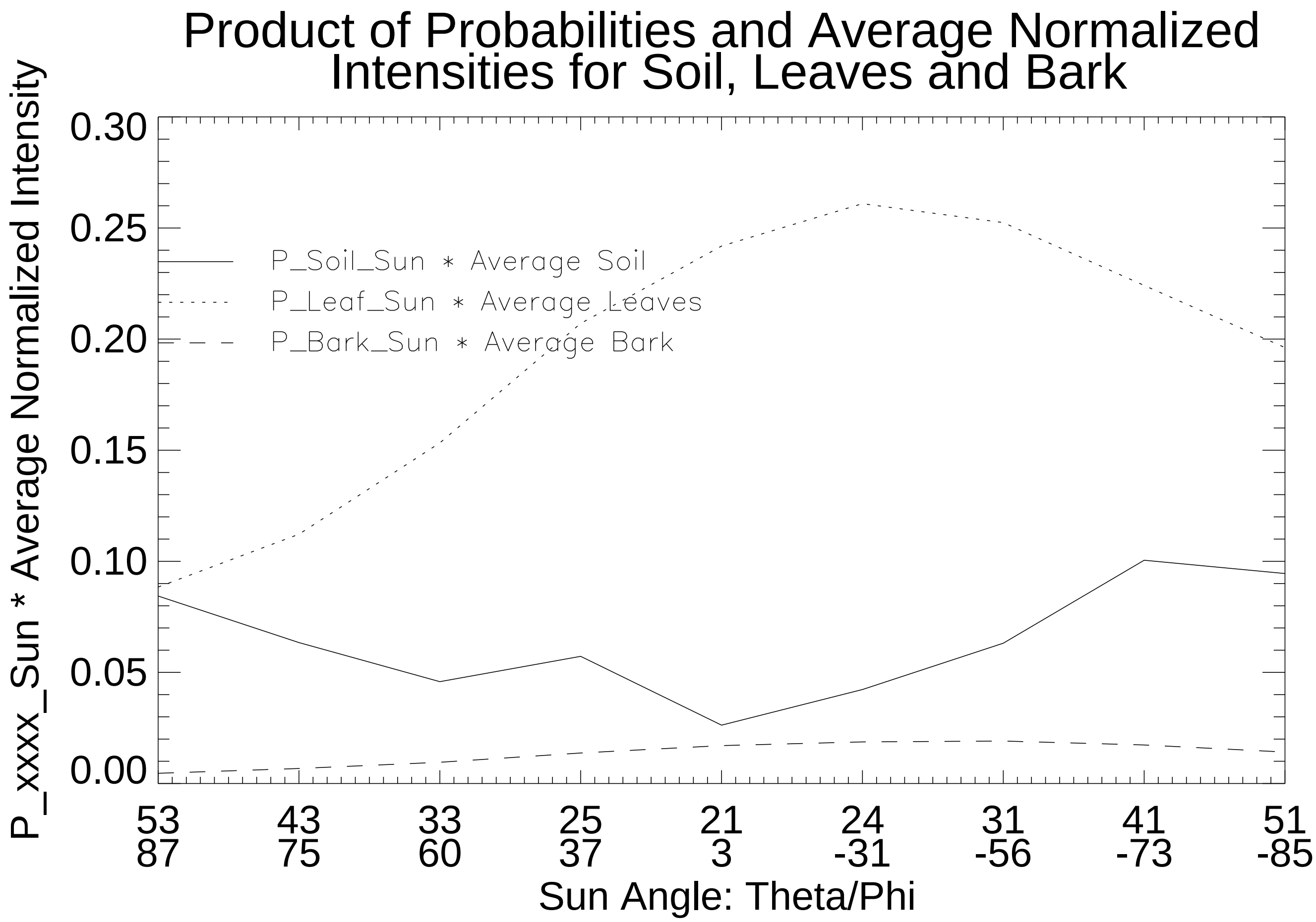
- Probabilities of seeing shaded surfaces :

  P^{shade}_{leaf}, P^{shade}_{bark}, P^{shade}_{soil}

- Average cosine of angle between the surface normal and sun vector for visible illuminated surfaces :

  $\overline{(\vec{n}_{leaf} \cdot \vec{n}_{sun})}$, $\overline{(\vec{n}_{bark} \cdot \vec{n}_{sun})}$, $\overline{(\vec{n}_{soil} \cdot \vec{n}_{sun})} = \cos\theta_s$


Probability to see Soil, Leaves and Bark
0.8
0.6
0.4
0.2
0.0
Probability
P_Soil_Sun
P_Soil_Shade
P_Leaf_Sun
P_Leaf_Shade
P_Bark_Sun
P_Bark_Shade
53 87
43 75
33 60
25 37
21 3
24 -31
31 -56
41 -73
51 -85
Sun Angle: Theta/Phi

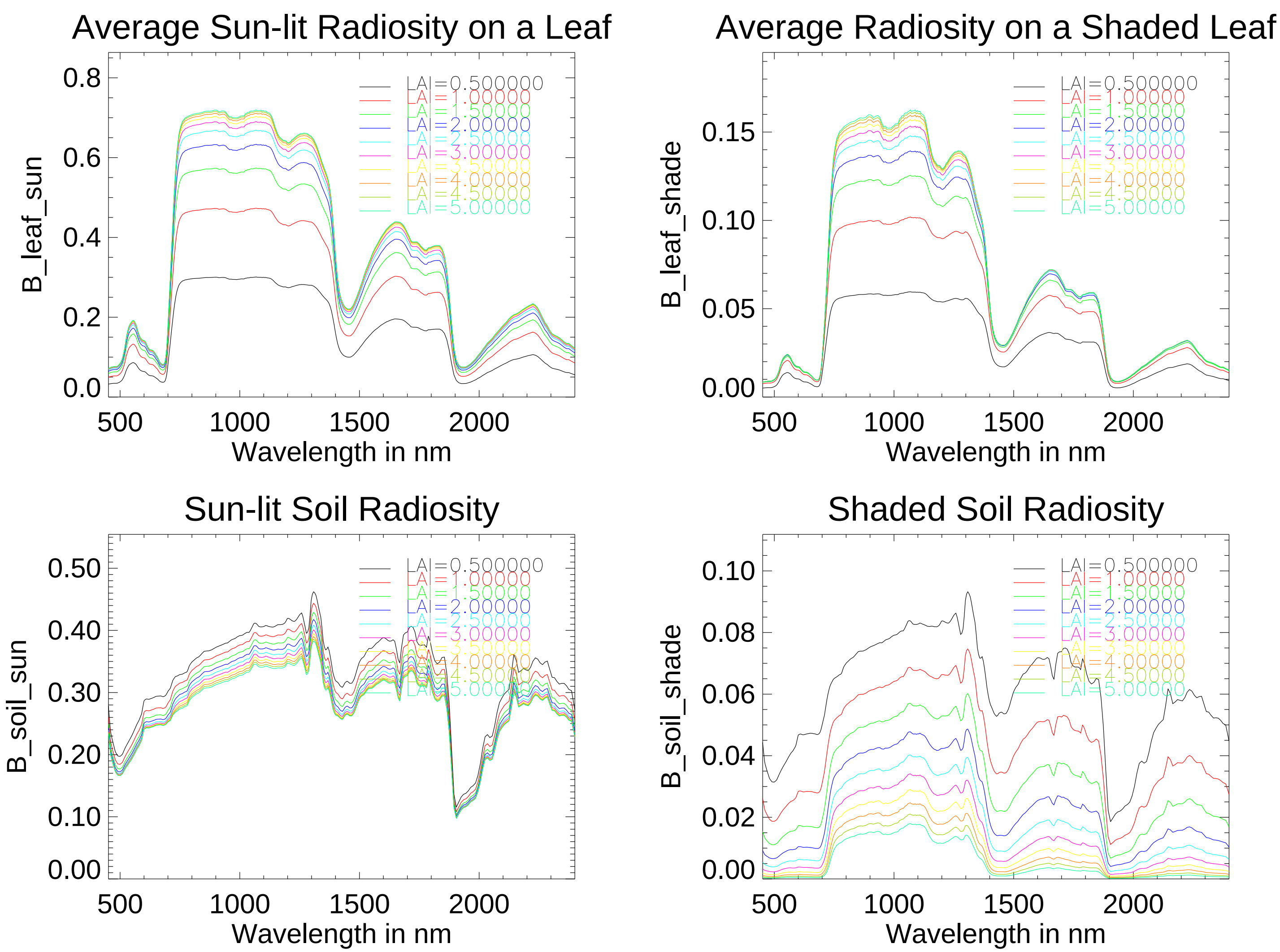

Product of Probabilities and Average Normalized Intensities for Soil, Leaves and Bark
P_xxxx_Sun * Average Normalized Intensity
0.30
0.25
0.20
0.15
0.10
0.05
0.00
P_Soil_Sun * Average Soil
P_Leaf_Sun * Average Leaves
P_Bark_Sun * Average Bark
53 87
43 75
33 60
25 37
21 3
24 -31
31 -56
41 -73
51 -85
Sun Angle: Theta/Phi

3. Approximate radiosities for the canopy by using the N-layer model with a total LAI similar to the walnut canopy ($LAI = 5$), measured leaf reflectances ρ and transmittances τ and assumed soil reflectance ρ_s ($\rho_{bark} = 0.$) :

$$\overline{B_{leaf}^{sun}} = \sum_{n=1}^{N} B_{leaf,n}^{sun} lai(1 - lai)^{n-1},$$

$$\overline{B_{leaf}^{shade}} = \sum_{n=2}^{N} B_{leaf,n}^{shade} lai(1 - lai)^{n-1},$$

B_{soil}^{sun} and B_{soil}^{shade}.


Average Sun-lit Radiosity on a Leaf
B_leaf_sun
Wavelength in nm
Average Radiosity on a Shaded Leaf
B_leaf_shade
Wavelength in nm
Sun-lit Soil Radiosity
B_soil_sun
Wavelength in nm
Shaded Soil Radiosity
B_soil_shade
Wavelength in nm
LAI=0.500000
LAI=1.00000
LAI=1.50000
LAI=2.00000
LAI=2.50000
LAI=3.00000
LAI=3.50000
LAI=4.00000
LAI=4.50000
LAI=5.00000

4. Approximate the spectral BRDF $f_{canopy}(\cdot)$ of the walnut canopy by :
$f_{canopy}(\theta_v, \phi_v; \theta_s, \phi_s; \lambda) =$

$$\frac{1}{E_0 \cos\theta_s}\Big[\, P_{leaf}^{sun}\overline{(\vec{n}_{leaf}\cdot\vec{n}_{sun})}\,\overline{B_{leaf}^{sun}} + P_{leaf}^{shade}\cos\theta_s \overline{B_{leaf}^{shade}}$$
$$+P_{soil}^{sun}\cos\theta_s \overline{B_{soil}^{sun}} \; + P_{soil}^{shade}\cos\theta_s \overline{B_{soil}^{shade}}\Big]$$

5. Plot spectral BRDF for given view/sun directions.

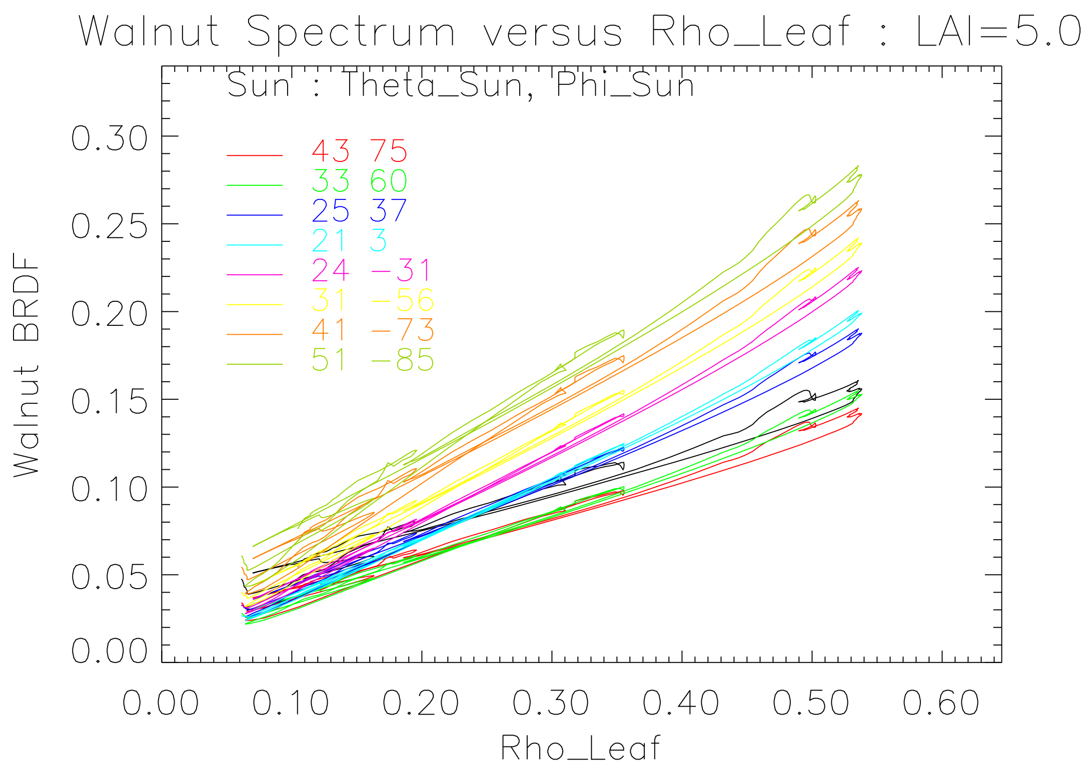
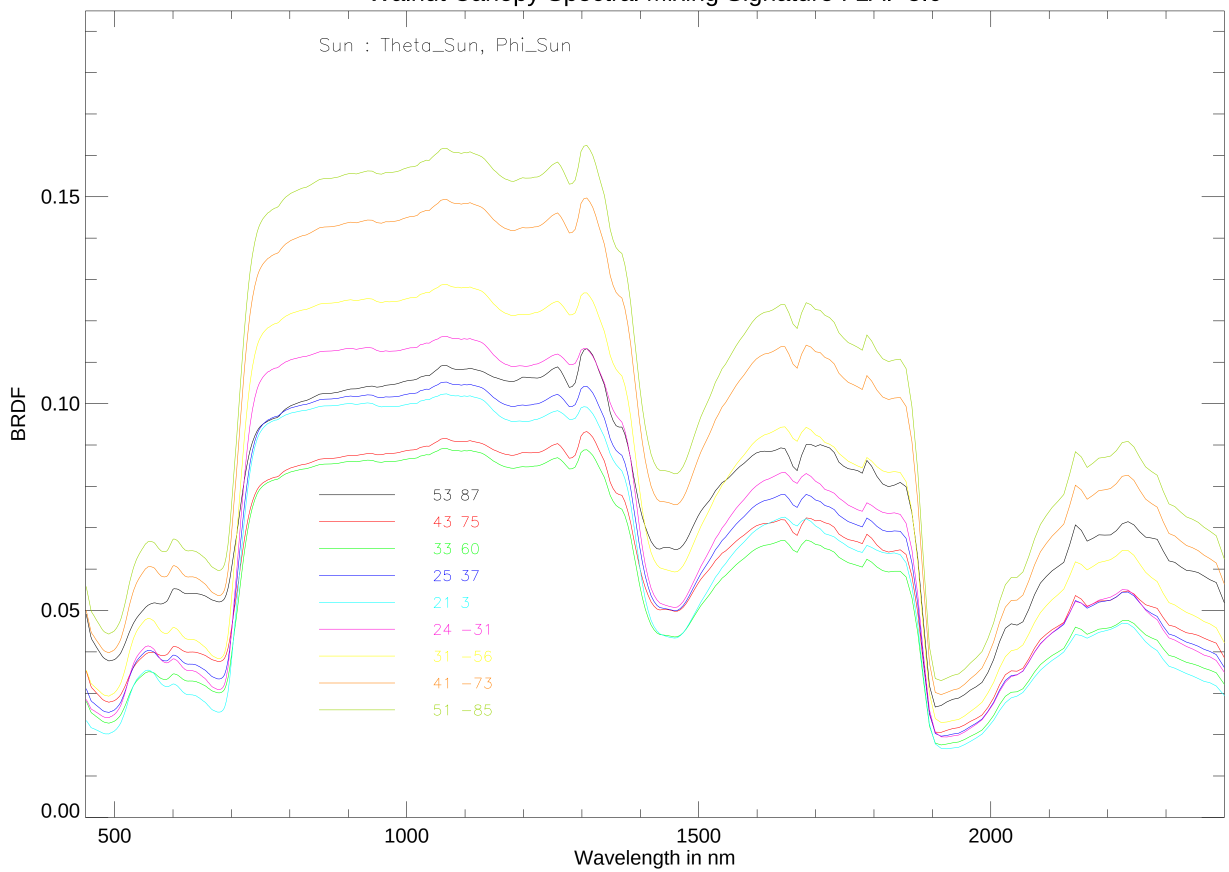


Figure 3: Canopy averaged BRDF for a walnut tree versus single leaf reflectance spectrum as a function of sun angles from 0.4 to 2.4 μm

ARE LEAF CHEMISTRY SIGNATURES PRESERVED AT THE CANOPY LEVEL?

Walnut Canopy Spectral Mixing Signature : LAI=5.0



Borel and Gerstl, LANL

Conclusions

- Radiosity models show nonlinear spectral mixing effects due to canopy architecture, varying illumination and viewing directions, soil ,bark, etc.
- For a given view direction and varying sun angles, the canopy architecture influences the probabilities of seeing illuminated surfaces and thus the spectral signature
- For a given sun angle and variable viewing directions, the canopy architecture has a small influence on the spectral signature

References

C.C. Borel, S.A.W. Gerstl and B. J. Powers. “The radiosity method in optical remote sensing of structured 3-D surfaces”, *Remote Sensing of the Environment*, 36:13-44, 1991.

N.S. Goel, I. Rozehnal and R.L. Thomson. “A computer graphics based model for scattering from objects of arbitrary shapes in the optical region”, *Remote Sensing of the Environment*, 36:73-104, 1991.

S.N. Martens, S.L. Ustin and J.M. Norman. “Measurement of tree canopy architecture”, *Int. J. Remote Sensing*, 12:1525-1545, 1991.